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# Litter manipulation strongly affects $CO_2$ emissions and temperature sensitivity in a temperate freshwater marsh of northeastern China

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ABSTRACT

Plant litter (including standing litter) modification plays a vital role in wetland carbon (C) balance, which can be greatly altered by global change. Our knowledge of the fundamental function of plant litter in ecosystem respiration (Re) is crucial for evaluating C exchange between the atmosphere and biosphere. However, it is not well understood how litter manipulation could influence the dynamics of Re and its temperature sensitivity ($Q_{10}$) in wetland ecosystems. In the present study, we conducted a field manipulation experiment with the following treatments of total aboveground plant litter removal (ALR), standing litter exclusion (AR), doubled plant litter (DL) and unchanged litter input (CK) to study the effects of wetland plant litter on Re and $Q_{10}$ values over two growing seasons (2015 and 2016) in a *Deyeuxia angustifolia*-dominated freshwater marsh in the Sanjiang Plain, Northeast China. Results showed that wetland Re was significantly affected by different plant litter input manipulations. During the two growing seasons, the Re ranged from 27.16 to 643.61 (ALR), 39.61–690.25 (AR), 136.27–1270.38 (DL) and 72.11–862.42 mg $CO_2$-C $m^{-2}h^{-1}$ (CK), which decreased by 28.36–68.04% and 15.11–63.23% of the ALR and AR treatments and increased by 15.41–20.59% of the DL treatment compared with CK, respectively. The changes in Re was more susceptible to litter removal effects. In 2016, the mean Re values of ALR and AR treatments decreased significantly compared with the corresponding values in 2015, while it was significantly increased in the DL treatment. The concentrations of $NH_4^+$ and DOC, as microbes directly used carbon and nitrogen sources in soil pore water were significantly affected by litter input manipulations suggesting that there are various carbon and nitrogen sources within and outside the plant litter. The $Q_{10}$ values of Re under each litter input manipulation treatment differed markedly, and the highest value (3.32–4.06) occurred in the total plant-derived litter input removal treatments indicating that the wetland soil was vulnerable to disturbance that prone to carbon losses in the context of global warming. Our results also demonstrated that the $Q_{10}$ values of the deeper soil (below 15 cm) with vegetation present were lower than that for the other litter removal treatments implying the important function of the carbon sink in this wetland ecosystem. Overall, we recommend that the role of wetland plant litter input to the soil system should be seriously considered when predicting biosphere-atmosphere C exchange model under the background of global climate change.

## 1. Introduction

Ecosystem respiration (Re), the main contributor of carbon (C) exchange between terrestrial ecosystems and the atmosphere, consists of autotrophic (plant) and heterotrophic (soil) respiration and, is very important in regulating climate systems and the global C balance (IPCC, 2013; Bond-Lamberty and Thomson, 2010; Davidson et al., 2006). Wetland ecosystems sequester approximately 37% of the global soil carbon in only 4–6% of the world land area, and they are expected to experience impacts from the strong changes in climate, which will also induce substantial feedbacks to the climate system (IPCC, 2013; Roehm, 2005). Despite the importance of atmospheric C sources, a forecast of the dynamics of wetland Re with climate change is obviously necessary, but our understanding of global constraints to Re and its sensitivity to changing climate conditions remain uncertain.

Factors affecting Re include abiotic (e.g., temperature and moisture) and biotic (e.g., substrates from plants and the microbes) factors in the environment. The relationships between Re and temperature have been

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studied by many scientists previously (e.g. Heimann and Reichstein, 2008; Kirschbaum, 2006). Kirschbaum (2006) suggested that respiration was greatly changed by altered temperature, who also noted that soil moisture and C substrate availability would limit the respiration process. Meanwhile, the temperature sensitivity ($Q_{10}$, changes in the respiration rate with a 10 °C temperature increase) of Re may also be altered due to the changes in carbon substrate availability (Gershenson et al., 2009; Kirschbaum, 2006). The decomposition and formation of soil organic matter is controlled by plant-derived materials input (litter/plant detritus, root exudates, etc.) and can be considered as the vital process in C cycling (Paul, 2016; Kuzyakov and Gavrichkova, 2010). Plant litter plays an essential role in regulating C exchange between the terrestrial biosphere and atmosphere. Previously studies have suggested that global warming can affect plant growth and vegetation composition and hence the plant-derived substances input to soil, which will alter the $CO_2$ exchange between atmosphere and biosphere as the substrate from plants will modify the microclimate that benefit for microbial activities (Leroy et al., 2017; Luo et al., 2017; Sayer et al., 2011; Schaefer et al., 2009). Cheng et al. (2010) found that changes in the quantity of litter production induced by global warming depend on the plant types, and that soil respiration was positively correlated with the amount of plant-derived C substrate input (Liu et al., 2009; Wu et al., 2017).

Northern wetland ecosystems play a vital role in the global carbon budget and have a great potential to mitigate global change. Wetland ecosystems in this area are net atmospheric $CO_2$ sinks due to the waterlogged, anoxic and cool conditions that reduce decomposition and result in the accumulation of soil organic C (Ström and Christensen, 2007). In these ecosystems with annual herbaceous plants as the dominant species, most of the plant biomass contributes to the soil substrate pools during litter fall and senescence processes greatly affecting the ecosystem C balance, which can induce the uncertainty related to predicting biosphere and atmosphere feedbacks in future scenarios (Zhao et al., 2016; Kayranli et al., 2010). To the best of our knowledge, many studies have been conducted to test the relationship between abiotic factors and soil respiration, and the litter manipulation effects on respiration in forest, steppe and agro-ecosystems. However, the responses of wetland respiration to changed detritus inputs into soil in wetland ecosystems have not been fully explored *in situ*. Based on these considerations, a plot-scale litter manipulation experiment was conducted in a typical marsh wetland in northeastern China. Our overall objective was to assess the effects of wetland plant litter manipulation on the dynamics of ecosystem respiration and its temperature sensitivities under changed litter inputs. In the present study, we hypothesized that 1) ecosystem respiration of the litter addition treatment would be higher than the controls and litter removal treatments as the microbial C substrate availability decreased, 2) the presence of wetland plant vegetation would increase the dissolved organic C concentration ([DOC]) due to the photosynthesis process transferred to the soil through the roots, 3) as the different stability of C source, the temperature sensitivity of respiration in the litter addition treatment would decrease compared to the litter removal treatments as C recalcitrance increased.

## 2. Material and methods

### 2.1. Site description

Our *in-situ* field observation experiment was carried out in a *Deyeuxia angustifolia*-dominated freshwater marsh at the Sanjiang Mire Wetland Experimental Station, Chinese Academy of Science, which is located in the center of Sanjiang Plain, Heilongjiang Province, northeastern China (47°35′N, 133°31′E; 56 m above sea level). The study site has a characteristic temperate continental monsoon climate, with a mean annual precipitation of 566 mm and a mean annual temperature of 2.5 °C (Mao et al., 2016). The frost-free period is approximately 125 days. The study site is a typical seasonally inundated freshwater marsh. The single dominant species is *Deyeuxia angustifolia*, and the occasionally occurring species are *Glyceria spiculosa*, *Carex meyeriana* and *Salix rosmarinifolia*. The soil type in this site is mainly a typical meadow mire soil based on the soil classification of China, and the soil organic C, N, and P concentrations at the surface (0–10 cm) soil depth are 114.08, 4.07, and 0.69 g $kg^{-1}$, respectively. The surface soil bulk density is 0.56 g $cm^{-3}$ and with a soil pH value of 4.95.

### 2.2. Experimental design

In late October 2014, the litter manipulation experiment was established when the wetland plants were all withering (standing litter). A total of 12 plots (1.5 m × 1.5 m each) were established in the *D. angustifolia* dominated freshwater marsh and have been maintained since they were established. Each plot was separated by an at least 1 m buffer zone to prevent human disturbance when sampling and measuring. The plot was fenced with stainless steel frame (1.5 m × 1.5 m, 0.5 m in depth) to avoid lateral seepage of the substance supplied by the plant-derived materials during observation. The experiment included four treatments with three replicates in a randomized complete block design, and the four treatments were as follows: 1) removal of total aboveground plant-derived litter input (including the standing litter and detritus on the soil surface) (ALR), 2) exclusion of the aboveground standing litter (AR), 3) doubling of the plant litterfall input (adding litter removed from ALR treatment, DL), and 4) unchanged litter input (CK). The aboveground plants in the ALR treatments were clipped from the soil surface, and the detritus was collected and redistributed evenly on the litter addition plots after being cut into 10 cm long pieces. The standing litter of the AR treatment was clipped and removed from the plots. The clipping process was periodically continued because of plant growth during our observations. Meanwhile, wooden boardwalks were established in advance around the plots to avoid human disturbance when sampling gas and water samples during the observations.

### 2.3. Ecosystem respiration (Re) measurements

The Re (C-$CO_2$ emission) was determined from 1 May to 31 September 2015 and 1 June to 10 October 2016. The measurement was conducted once every 10 d interval in 9–11 a.m. at sunny and windless weather condition. The $CO_2$ emission was determined using the static chamber-gas chromatographic method in each plot with differed litter input treatments, and the $CO_2$ fluxes were calculated according to the linear changes in the dark chamber over time (Song et al., 2009). The static chamber consisted of two parts made of stainless steel. Before the $CO_2$ efflux measurements were taken, the stainless steel base (0.5 m × 0.5 m) was buried into the soil at a depth of 0.2 m in each plot and permanently installed in the soil for the entire observation period. Five air samples of 30 ml each were taken from the stainless steel chamber by syringes equipped with three-way stopcocks every 10 min after sealing the chamber in 40 min. All the gas samples were brought to the laboratory and analyzed with the gas chromatograph (GC, Agilent HP4890) within 12 h.

### 2.4. Soil temperature and moisture

During the observation period, the air temperature inside and outside the chamber was determined with a digital thermometer (JM624, JinMing Instrument Co., Tianjin, China) at the beginning and end of the sampling time to calculate the $CO_2$ efflux. Meanwhile, soil temperature and moisture in the different treatment plots were also determined concurrently with respiration. Soil temperatures at soil depths of 5, 10, 15, 20, 25 cm were measured with a precise geothermometer, and they were kept at the different soil depths during the entire observation period. Soil moisture was measured with a portable TDR (Trime-PICO32, IMKO Co., Germany) at 3 random points around the

respiration chambers at a 10 cm soil depth.

### 2.5. Soil pore water sampling and measurement

The soil pore water at 0–10 cm depth was periodically sampled according to the method proposed by Höll et al. (2009) in each of the twelve plots. Approximately 100 ml of soil pore water was collected in plastic bottles, transported to the laboratory as soon as possible, and then filtered within 12 h through a 0.45 μm membrane filter and stored at 4 °C before the chemical analysis. For the soil pore water, the nitrate ($NO_3^-$) and ammonium ($NH_4^+$) contents were measured by the hydrazine reduction method and sodium salicylate-sodium hypochlorite method using a continuous-flow autoanalyzer (AA3, Seal Analytical, Germany). The dissolved organic carbon (DOC) concentration in the soil pore water was performed by the NPOC method using a multi C/N 2100 analyzer (Analytik Jena, Germany). In addition, the absorbance value of the soil pore water at 254 nm ($Abs_{254}$) was obtained by the ultraviolet spectrophotometer.

### 2.6. Curve fitting

The non-linear regression was used to examine the relationship between $CO_2$ emissions of different litter input treatments with soil temperature at various depths and the surface soil volumetric water content. The relationship between Re and soil temperature at different soil depths was expressed as an exponential function (Lloyd and Taylor, 1994):

$$Re = ae^{bT} \quad (1)$$

where $Re$ refers to ecosystem respiration rate (mg C-$CO_2$ $m^{-2}h^{-1}$), $a$ and $b$ are the empirical coefficients, and $T$ is the soil temperature (°C) at soil depths of 5, 10, 15, 20, 25 cm in our study.

The $Q_{10}$ value was calculated as

$$Q_{10} = e^{10b} \quad (2)$$

where $b$ is the value from Eq. (1).

### 2.7. Statistical analysis

The daily $CO_2$ emission was calculated from the gas samples sampled at 9–11 a.m. of each litter input manipulation treatment every time during the observed period. The cumulative $CO_2$ flux was obtained by combining the $CO_2$ emissions from every month during the measured period. Monthly variations in Re from the different litter manipulation treatments were determined by the daily arithmetic mean values that was measured on the same day. One-way ANOVA was used to test the differences in soil temperature and moisture of each treatment. The repeated-measures ANOVA was used to examine the effects of varied litterfall manipulation on ecosystem respiration, DOC, $Abs_{254}$, $SUVA_{254}$ and inorganic N contents over the observation period at the significant level of $p < 0.05$. All the statistical analyses were performed with SPSS 11.0 (SPSS Inc., Chicago, USA). Significant differences were considered at the $p < 0.05$ level.

## 3. Results

### 3.1. Variations in environmental factors

The air temperature and daily precipitation showed seasonal dynamics in both years (Fig. 1). Monthly average temperature exhibited an increasing trend from May (12.26–13.31 °C) to August (20.44–21.93 °C) and then decreased until late September (14.65–14.71 °C). Daily rainfall also showed a seasonal dynamic, but with different patterns (Fig. 1). In 2015, more than 57% of the rainfall occurred in short and heavy bursts in June and July that resulted in the one peak pattern. In 2016, however, it was more than 67% of the daily precipitation occurred in May, July and September, which exhibited two peaks pattern that different from the year of 2015.

The temporal variations in soil temperature at different depths also showed seasonal dynamics and exhibited a similar trend with air temperature (Fig. 2a). Soil temperature of the ALR treatment was significantly higher than that of any other treatments ($p < 0.05$). Compared with the controls, soil temperature was also increased in the AR treatment, but significantly decreased in the DL treatment ($p < 0.05$). Soil moisture also showed the similar trends, but exhibited an opposite characteristics with temperature (Fig. 2b). In our study, the mean surface soil water contents of different plant litter input manipulations were 58.95–65.73% and 60.54–68.12% in 2015 and 2016, respectively. Litter manipulation did not significantly influence the top 0–10 cm soil moisture content (Fig. 2b), which may be attributed to the soil evaporation and plant transpiration and the seasonal flooded characteristic of marshland ecosystem.

### 3.2. Dynamics of ecosystem respiration (Re)

The temporal dynamics of Re rates showed clearly fluctuations in monthly variations during observation (Fig. 3a). The mean Re rates of different treatments were 311.78–514.20 mg C-$CO_2$ $m^{-2}h^{-1}$ and 210.21–739.36 mg C-$CO_2$ $m^{-2}h^{-1}$ in 2015 and 2016, respectively. The results of repeated measurements of ANOVA showed that Re was significantly increased in the DL treatment and significantly decreased in the ALR and AR treatments over the observed period ($p < 0.01$, Table 1). The cumulative Re fluxes of different treatments are shown in Fig. 3b. Compared with the controls, the Re fluxes of the DL treatment was increased by 15.41% and 20.59% in 2015 and 2016. The increment in the second year was higher than that of the first year, but there were no statistically significant differences ($p > 0.05$). Meanwhile, the ALR and AR treatments significantly decreased the respiration fluxes, especially in the second year (more than 60%).

### 3.3. Chemical properties of the pore water

The chemical properties of the surface 10 cm soil pore water are shown in Figs. 4, 5. The [DOC] of the soil pore water had marked seasonal dynamics and was significantly affected by different litter input treatments (Fig. 4a). The mean [DOC] of the ALR, DL, CK and AR treatments determined during the observation periods were 24.25, 22.01, 20.48 and 23.54 mg $L^{-1}$ in 2015, and 20.33, 17.55, 17.28 and 20.52 mg $L^{-1}$ in 2016. The [DOC] were significantly increased in the litter removal treatments ($p < 0.05$). The absorbance values of pore water at 254 nm ($Abs_{254}$, an indicator of the concentration of colored DOC; Jones et al., 2016) are shown in Fig. 4b. The measured $Abs_{254}$ variation tendency was similar to the DOC changing dynamics in the four treatments. The mean absorbance value of the CK treatment was the lowest (0.86) in 2015, while it occurred in the ALR treatment (0.84) in 2016, reflecting the changes in the supply of labile C under different litter input manipulations (Fig. 4b). The specific UV absorbance ($SUVA_{254}$) was calculated as the ratio of $Abs_{254}$/DOC, implying the highly colored character of the DOC in the pore water. In this study, litter input manipulations had significant effects on $SUVA_{254}$ values that ranged from 0.03 to 0.08 L $mg^{-1}$ during the measured time ($p < 0.05$). Generally, the low ratio of $Abs_{254}$/DOC indicated that the DOC was unlikely to be degraded, resulting in the accumulation of DOC in the soil pore water, which was notably exhibited in the litter removal treatment (Fig. 4c).

Fig. 5 shows the dynamics of $NH_4^+$ and $NO_3^-$ in the soil pore water during the observations. The $NH_4^+$ concentration showed different temporal dynamics and was significantly increased in the litter removal treatment ($p < 0.05$, Fig. 5a). In 2015, the $NH_4^+$ concentration exhibited a decreasing trend, while it was increased and then decreased until the end of the experiment in 2016. Meanwhile, litter input manipulation did not significantly affect the $NO_3^-$ concentrations over the

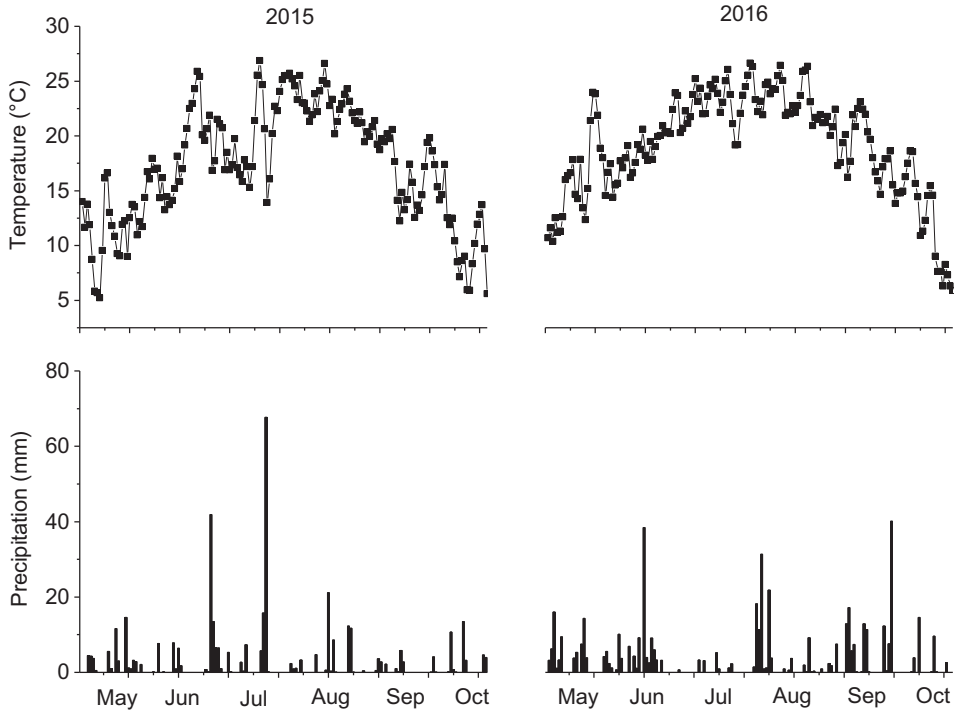


**Fig. 1.** Daily air temperature (black line) and precipitation (black bars) during the observation period in 2015 and 2016.

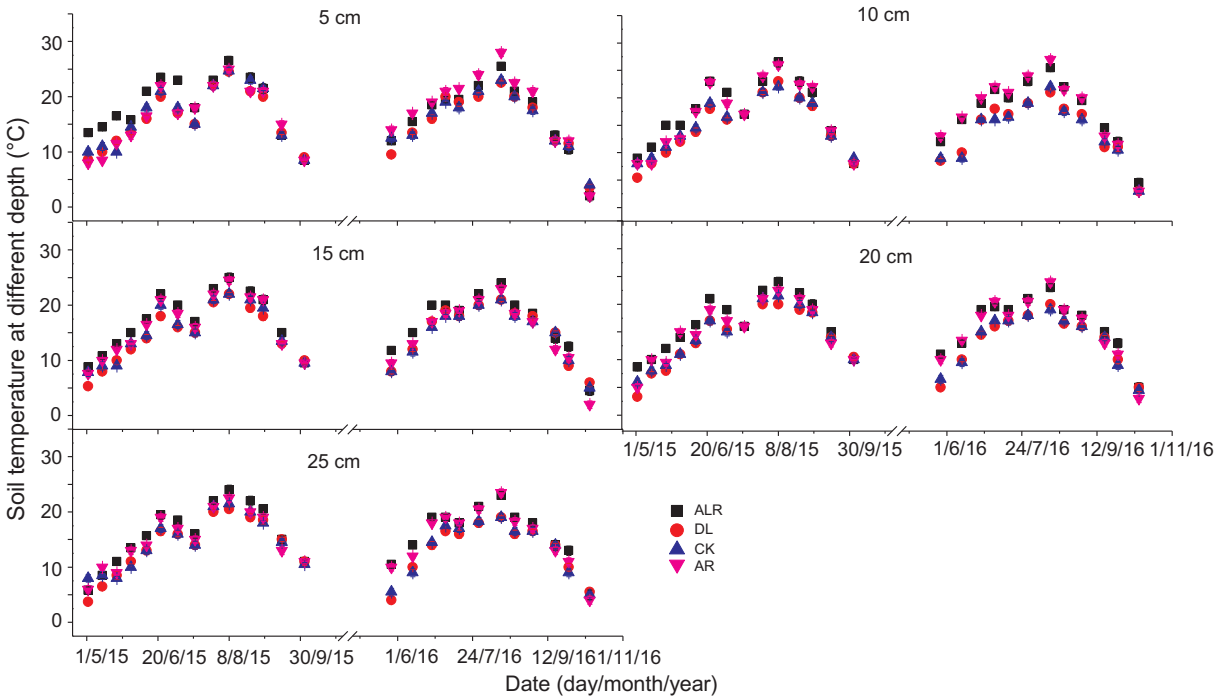


**Fig. 2a.** Temporal variations in soil temperature at different depths under varied litter manipulation treatments. ALR, total aboveground plant litter removed; DL, doubling plant litterfall input; AR, exclusion of aboveground standing litter; CK, controls. Values are Means ± SE, which are the same below.

observation period. The $NO_3^-$ concentrations were significantly higher than that of $NH_4^+$ concentrations under different litter input manipulation treatments, regardless of the treatment type and time ($p < 0.05$).

### 3.4. The relationships between temperature, moisture and Re

The Re rates were significantly correlated with soil temperature and moisture under every litter input manipulation treatments during observation periods (Fig. 6, $p < 0.05$). Considering the four treatments, Re and temperature at different soil depths into consideration, Re showed a significant positive exponential correlation with soil temperature ($p < 0.001$). The relationship between Re and the top 10 cm soil moisture was fitted with a polynomial model that the higher Re occurred at the moderate soil moisture content of the DL, AR and CK treatments, while the water content had a significant negative effect on Re in the ALR treatment, which was different from other treatments (Fig. 6 below). Effects of litter input manipulations on $Q_{10}$ values of Re

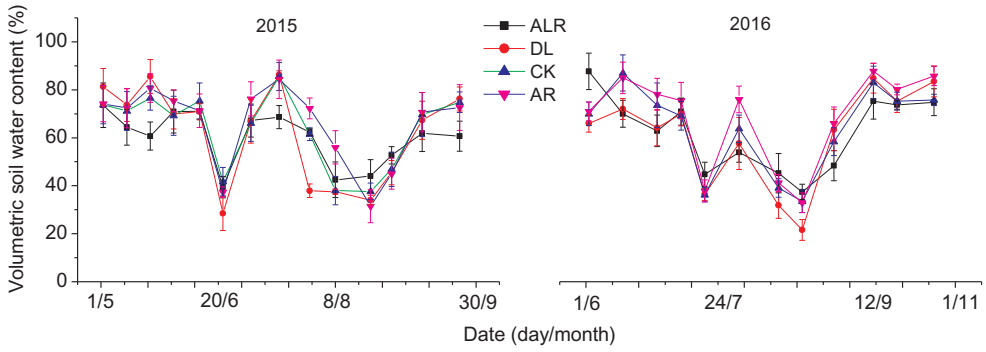


**Fig. 2b.** Temporal variations in surface soil moisture under different litter manipulation treatments.

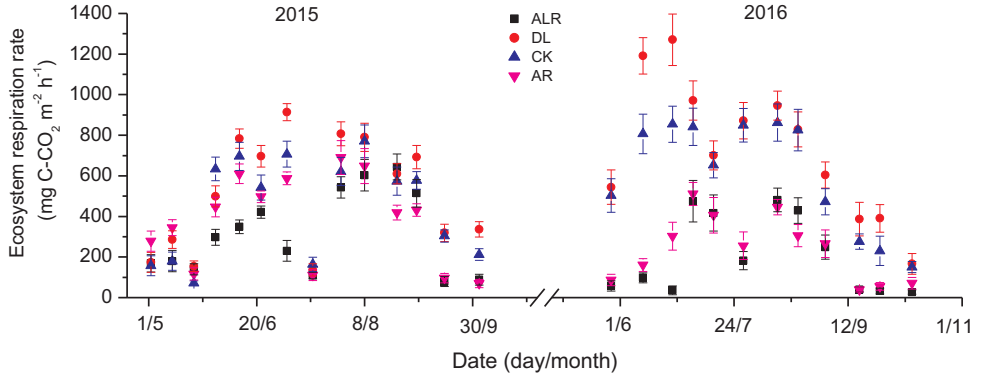


**Fig. 3a.** Ecosystem respiration rate measured under different litter manipulation treatments during the observation period in the Sanjiang Plain, northeastern China.

depended on the treatment type and soil depth. The $Q_{10}$ values ranged from 1.82 to 4.06 for the four treatments in the five soil layers. The $Q_{10}$ value of Re was not significantly changed by the DL and AR treatments at the surface 10 cm soil depth in this study, but it was significantly increased by the ALR treatment (Fig. 6, $p < 0.05$). Compared to the CK treatment, the $Q_{10}$ values were greatly increased in the ALR, DL and AR treatments, especially in the ALR treatment with soil depths of 15, 20 and 25 cm.

## 4. Discussion

Our observation results showed that litter input manipulations had significant effects on ecosystem respiration in this wetland ecosystem (Figs. 3a, b). Consistent with other previous litter input manipulation experiments (Sayer et al., 2011; Wang et al., 2013; Wu et al., 2017), our results revealed that Re increased by 15.41% in the doubling plant litter input treatment and decreased by 28.36% and 15.11% in the removal of all plant-derived litter and residue inputs and the exclusion of above-ground standing litter treatments in the first year. The corresponding values were 20.59%, 68.04% and 63.23% in the second year, which was consistent with our first hypothesis. Plant litter as the major source of soil organic matter contains numerous C forms of different degradability can strongly affect the microbial substrate availability and hence the C cycling (Van Groenigen et al., 2017; Cotrufo et al., 2013; Leff et al., 2012; Schaefer et al., 2009). The input of labile C from the plants could "prime" the microbial activities that decompose fresh C and break down the native C compounds increasing the $CO_2$ flux to the atmosphere (Kuzyakov, 2002). Meanwhile, if the labile carbon inputs terminate or decrease, the soil respiration rates will decline (Six et al.,

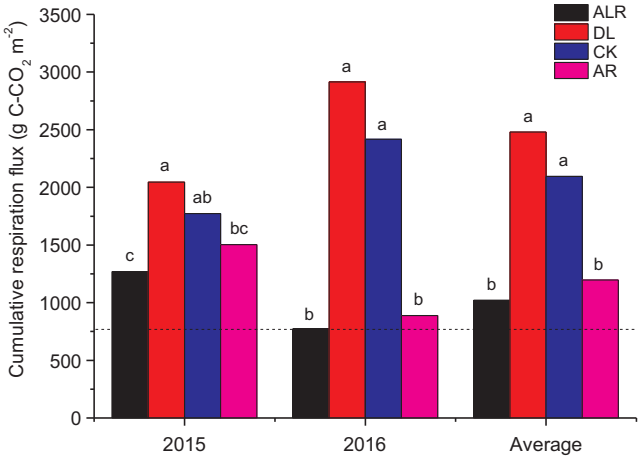


**Fig. 3b.** Cumulative respiration fluxes of varied litter manipulation treatment in 2015 and 2016. Small letters represent significant differences among different treatments at the $p < 0.05$ level.

**Table 1**
Results (*F*-values) of the effects of litter input manipulation treatments, sampling time and their interactions on ecosystem respiration (Re) rate, DOC, $Abs_{254}$, $NH_4^+$ and $NO_3^-$ based on the repeated measures ANOVA ($^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$; *ns* not significant).

| Source | Re rate | DOC | $Abs_{254}$ | $SUVA_{254}$ | $NH_4^+$ | $NO_3^-$ |
|---|---|---|---|---|---|---|
| Treatment | $91.42^{***}$ | $8.65^{**}$ | 2.83 *ns* | $4.97^{*}$ | $80.64^{***}$ | 3.63 *ns* |
| Time | $54.88^{***}$ | $65.22^{***}$ | $25.99^{***}$ | $14.17^{***}$ | $57.86^{***}$ | $38.15^{***}$ |
| Treatment × Time | $7.99^{***}$ | $5.36^{***}$ | $4.16^{***}$ | $3.26^{***}$ | $11.10^{***}$ | $3.06^{***}$ |

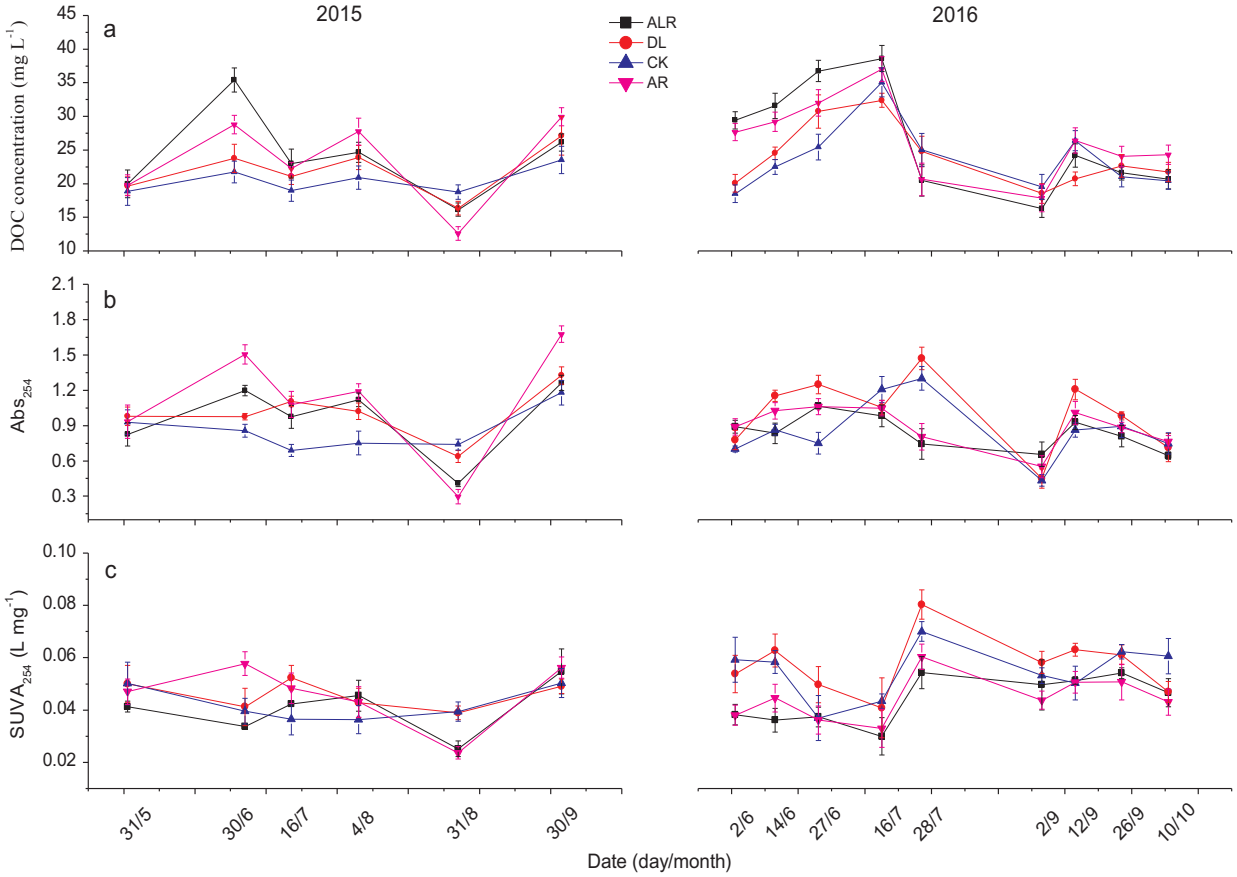


**Fig. 4.** Mean DOC concentration, 254 nm absorbance and the $SUVA_{254}$ values of the surface soil pore water under varied litter input manipulation treatments during the observation period.

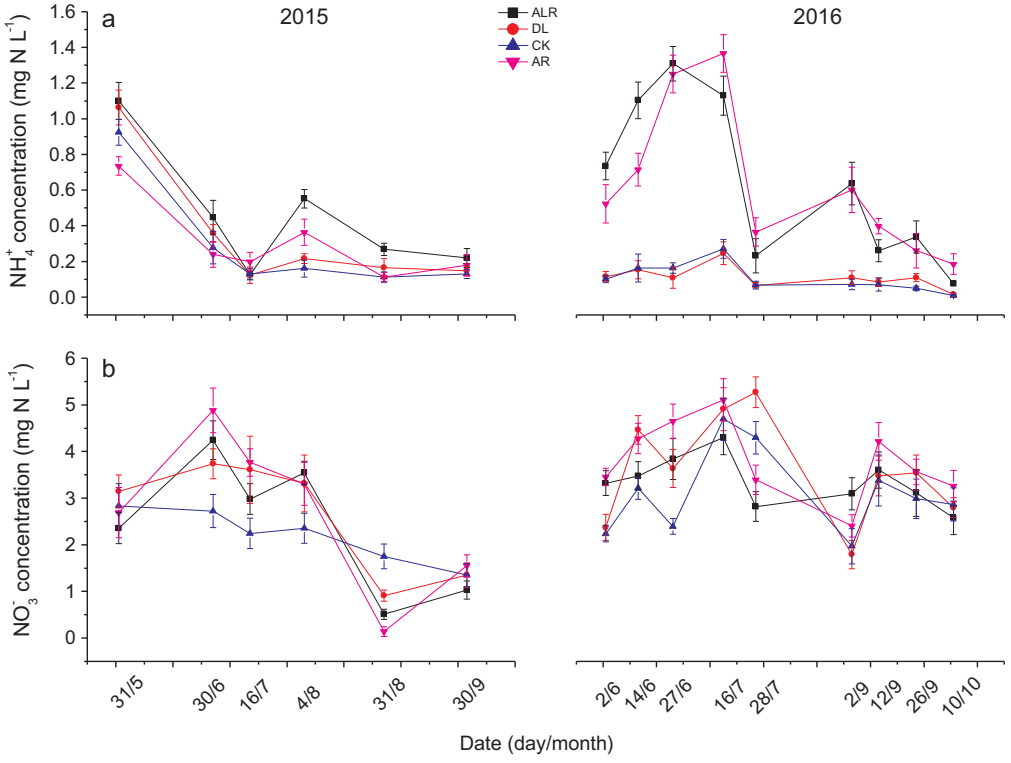


**Fig. 5.** Dynamics of $NH_4^+$ and $NO_3^-$ in the top layer (10 cm) of soil pore water under varied litter input manipulation treatments during the observation period.

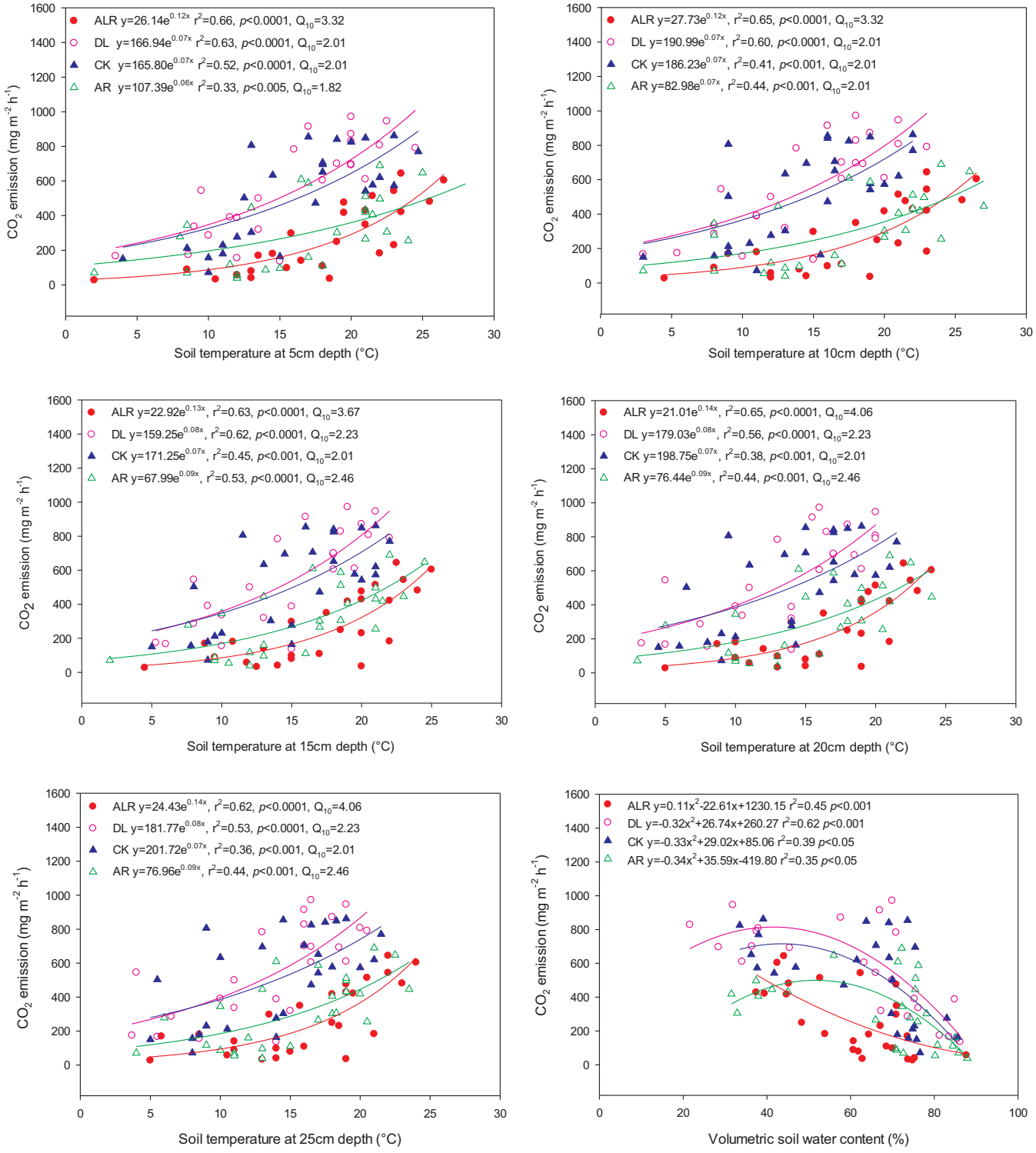


**Fig. 6.** Relationships between soil temperature, moisture and $CO_2$ emission rates for different litter input manipulation treatments during the observation period.

2002). In the litter removal treatments, the labile C from the litter leachates was lower than that in the litter addition treatment, and the photosynthesis transferred to the soil was lower, greatly reducing Re (Kuzyakov and Blagodatskaya, 2015; Leff et al., 2012). This consequence was also supported by our soil pore water incubation experiment at the end of the field observation experiment, indicating that litter removal caused lower $CO_2$ emissions than the litter addition and control treatments (data not shown). Meanwhile, another explanation for the higher $CO_2$ flux in the litter addition treatment was the microbial N mining theory that stimulating native soil C mineralization in nutrients limited wetland ecosystem (Mao et al., 2016). We found that litter amendment induced the significant reduction in $NH_4^+$ content as microbes usually preferentially utilized $NH_4^+$ and hence more C engaged in biogeochemical process in this wetland ecosystem.

We found that increased Re flux induced by doubled litter addition was substantially lower than that from the removal of aboveground litter and residues in the second year. This phenomenon was similar to the results of the study by Wu et al. (2017), who deemed that the

priming effect induced by litter addition was negligible relative to a short time interval after litter manipulation. In this seasonal flooded marsh wetland, the stimulated impacts of litter addition on Re may also be inhibited by the moisture conditions. The Re includes autotrophic (plant) and heterotrophic (soil) respiration, which respond differently to vegetation and climate change. The augmentation of soil respiration can be independent of any compensatory process in plant production (Hicks Pries et al., 2013; Hartley et al., 2012). We did not separate autotrophic and heterotrophic respiration as it is impossible to remove the belowground roots in this wetland ecosystem. The role of wetland plant root system in Re was not totally clear. The effects of plant-derived substrate (litter input and root exudate/decomposition and their interactions) on the dynamics of soil C pool should be considered when evaluating the C cycling and balance between the biosphere and atmosphere (Paul, 2016).

In contrast to our second hypothesis, the presence of wetland plant vegetation decreased the [DOC] compared to the litter removal treatment (Fig. 4a), which was in accordance with previous studies (Leroy et al., 2017; Freeman et al., 2004). Leroy et al. (2017) found that the presence of *Molinia caerulea* significantly decreased the [DOC] compared to *Sphagnum* moss in a peatland, and they suggested that the degradation of the labile DOC directly used by the microbes from plant photosynthetic products transferred to the roots was enhanced by the stimulated microbial activity, leading to the consumption of DOC in the peat soil (Basiliko et al., 2012). Meanwhile, the DOC produced by photosynthetic activity is usually with high microbial availability that of low molecular weight, transparent and thus easily consumed, resulting in the decrease of DOC in the vegetation present treatments and thus more C emission (Brock and Clyne, 1984). In addition, we found that the absorbance values of the varied litter input manipulation treatments were different and showed seasonal dynamics (Fig. 4b), reflecting the change in the carbon substrate source and microbial availability during the observation period.

Soil temperature and moisture are important abiotic factors controlling terrestrial ecosystem carbon cycle (Risch et al., 2013; Bond-Lamberty and Thomson, 2010). However, the effects of litter input manipulation on the relationships between $CO_2$ emission and temperature/moisture in wetlands are not clear. Our results revealed that there was a significant exponential correlation between Re and soil temperature at different depths, which was similar to other studies (Leroy et al., 2017; Wu et al., 2017; Zhu et al., 2015). In the removal of total plant-derived litter input treatment, the $Q_{10}$ values of all soil depths were significantly increased compared with other litter input treatments, and they were also increased in the standing litter removed treatment of the 15–25 cm soil layer (Fig. 6), suggesting that wetland soil in this layer with vegetation present as a potential pool was not particularly vulnerable to global warming. Leroy et al. (2017) also found that the sensitivity of $CO_2$ emission to temperature was decreased with peatland plants present, demonstrating the vital role of wetland plant in maintaining terrestrial carbon pool. Previous studies suggested that there was a weak correlation between Re and moisture if little variation in moisture content was found during observation (Leroy et al., 2017; Zhu et al., 2015). In this study, we fitted a polynomial model between Re and surface soil moisture, which was consistent with the research conducted in a forest ecosystem (Wu et al., 2017). Our experiment was set up in a seasonal flooding marsh and the volumetric moisture content of the surface 10 cm soil had a wide range during measurement (Fig. 2b). The $CO_2$ peaks occurred at lower soil moisture contents when microbial substance availability increased as the plant derived C input maybe the main factor regulating microbial activity (Yuste et al., 2007). The thickness of the organic layer will increase with the increase in plant litter inputs and can moderate the soil temperature and moisture that benefit the microbial mineralization process (Fekete et al., 2016). Meanwhile, in the range of the observed soil water contents, Re increased with decreased moisture content in the removal of all plant-derived litter (i.e. standing litter and detritus on the soil surface) input treatment during observation, which indicates the important function of wetland plants in maintaining the stability of soil C pool. As a special terrestrial ecosystem, the interactive effects of soil temperature, moisture and plant-derived materials on wetland ecosystem C exchange and budget should be considered when predicting its response and feedbacks to global change.

## 5. Conclusions

Wetland plant litter input had significant effects on ecosystem respiration and its temperature sensitivity in this seasonal inundated wetland ecosystem. Litter removal significantly decreased ecosystem respiration (15.11–68.04%), while it was significantly increased (15.41–20.59%) in the litter addition treatment during observation. The decrement or increment of Re in 2016 was higher than that in 2015 and Re was more susceptible to litter removal effects. The concentrations of $NH_4^+$ and DOC as microbes directly used energy source and the specific UV absorbance ($SUVA_{254}$) of soil pore water were significantly influenced by litter input manipulation treatments implying diverse carbon and nitrogen availability in the soil-plant system. The $Q_{10}$ values of Re under each treatment differed markedly that depending on plant litter manipulation and soil depth. Overall, both biotic (plant-derived material) and abiotic (temperature and moisture) factors control Re and they can interact with each other to change the sensitivity of $CO_2$ emission to temperature in this wetland ecosystem. The function of plant root in Re was not clarified as the intricate root system belowground. Our study advocates the important role of wetland plant litter in regional carbon budget prediction and the accompanied variation in $Q_{10}$ values in response to climate warming.

## Declarations of interest

None.

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